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CAM PLASTOMETER: OPERATIONAL STATUS AND PLANS FOR UPGRADING

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PHYSICAL METALLURGY RESEARCH LABORATORIES
REPORT: MRP/PMRL 82-55(TR)

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by

D.L. Baragar

ABSTRACT

A series of tests have been completed to assess the operating condition of the Cam Plastometer as a prelude to an extensive research program on the hot flow stress behaviour of steels. The steel chemistry and test conditions were selected to duplicate some tests carried out when the Cam Plastometer was first commissioned, ten years ago. The agreement between the two sets of stress-strain data is excellent indicating that the system is operating according to design specifications.

Further tests were carried out to determine the reproducibility of the stress-strain data and the effects of friction. First, ten tests were made at the same temperature and strain-rate and confidence intervals were calculated from the standard deviation in stress at a strain of .35. The 95% confidence interval for the measured stress is found to be ±3%. Second, the effect of friction on stress-strain data was determined by deforming samples with and without lubrication. No significant or consistent difference in the two sets of data was evident. It is concluded that a correction factor as applied in earlier work is not necessary.

A primary objective of future work on the Cam Plastometer is simulation of the hot rolling of strip. Some specific proposals to upgrade the operational capabilities and experimental scope to meet this objective are described. Modifications will be required to the data aquisition method, system activation technique, screw down mechanism, sample cooling control and the cam design. Potential design changes in these areas are suggested.

INTRODUCTION

The specifications for steel used in pipelines, offshore structures and other energy related projects are changing rapidly to meet the demands created by increasingly stringent operating requirements. Consequently, new alloys, such as high strength low alloy steels, are under development, for which rolling loads and optimum rolling schedules must be determined.

A cost effective method of obtaining this information is by applying rolling theory using hot flow stress data determined in the laboratory. The relationship

$$\sigma = f(\varepsilon, \dot{\varepsilon}, T, M, C)$$

between stress, σ, strain, ε, strain rate $\dot{\varepsilon}$, temperature T, microstructure, M, and composition C, can be determined on several types of testing machines. These machines differ, mainly, in the manner in which the load is applied: torsion, tension and compression. The Cam Plastometer is a compression testing machine specially designed to deform specimens at a constant true strain rate of .5 to 250 s^{-1}.

The design of the Cam Plastometer at EMR was based on that of the plastometer at the Los Alamos Scientific Laboratory (1). Earlier work by Stewart described the construction and operation of the plastometer, and its use in hot deformation studies on C-Mn and HSLA steels (2,3,4). The machine is limited, in its present condition, to two compressive deformations with minimum inter-hit times of 15 s, only one of these hits being at a constant true strain. These limitations severely restrict the usefulness of the Cam Plastometer for obtaining suitable data in the prediction of strip-rolling requirements.

The object of the preliminary stage of this project therefore is two-fold:

1. To establish that the Cam Plastometer is operating according to original design, and that the data obtained is accurate and reproducible.
2. To determine how the Cam Plastometer can be modified to effect four successive hits at a constant true strain rate and with inter-hit times of about 1 second.

This work is discussed in the following two sections beginning with a general description of the operation of the Cam Plastometer.

CAM PLASTOMETER OPERATION

Machine description

A cylindrical specimen is deformed between two flat dies within a heavy, two-column machine frame (Fig. 1(a), (b). The lower die, K in Fig. 2 is caused to move upwards by a cam follower, I, and transfer block J. The profile of the cam lobe, P, is such that a constant true strain rate if imposed throughout the test. Details of the theory of the cam design are given elsewhere (2). The upward movement of the lower die compresses the sample and the total deformation is complete in one pass of the cam lobe.

The plastometer drive train must rotate the cam at the proper speed to produce the desired strain rate and maintain this speed during the deformation. The drive train consists of a 29828 W variable speed electric motor driving the cam and fly wheel through two multi-speed transmissions (Fig. 3). The two transmissions allow the cam to be rotated at speeds from 10 to 2500 rpm. The rotational speed is monitored by a magnetic pick-up acting on a 60-tooth gear on the flywheel shaft.

The cam follower must take its position between the cam and the transfer block for only one pass of the lobe. Therefore, a cam follower activation system was designed to insert the cam follower, allow the deformation to occur and then retract the follower before the lobe returns.

During deformation, loads are measured by a strain gauge load cell. The cell, capacity rating 13825.5 N is bolted to the underside of the main screw-down. The four-arm strain gauge bridge is excited by a Bridge Amplifier Meter. The output signal, proportional to the load, is fed to a Biomation transient recorder which converts the analogue signal to digital and stores the data.

Test samples are heated in a globar furnace separate from the plastometer. The temperature drop during the transfer of the sample is reduced by radiation shields shown in Fig. 4. The assembly consists of a base on which the sample is mounted and two radiation shields which surround the sample. An inert atmosphere can be provided for the sample. Temperature is measured by a thermocouple which is inserted into a hole one half its radius in depth, drilled horizontally into the sample at mid-height.

Test results

The first series of tests were done on one material at the same temperature and strain rate. A measure of test reproducibility was found from this data, by calculating the standard deviation in the measured stress at a strain of .35. These values are listed in Table 1. The calculated 95% confidence limits of 118.9 ± 3.58 (±3.01%) demonstrate a high level of reproducibility similar to the accuracy (±4.5%) achieved by Hockett (1). The results of tests made by Stewart (5) on this same steel at the same temperature and strain rate are listed in Table 2. A comparison of the average stress from Tables 1 and 2 shows good agreement, indicating that the plastometer is operating according to the original operating design.

Further confirmation that the plastometer was functioning properly was obtained by deforming a C-Mn alloy (Table 3) at three strain rates and three temperatures and comparing these results with those of Stewart for the same test conditions (3). These results are plotted in Figs. 5, 6 and 7. For the strain rates of 2 s^{-1} and 20 s^{-1} the flow curves as determined by Stewart and the recent tests, are in good agreement. However, at a strain rate of 140 s^{-1} the agreement is less good.

No lubrication was used in either set of tests. The load required for a deformation to a given strain, with friction present can be greater than the load required for homogeneous deformation. Stewart initially corrected the measured stress using a factor dependent on the degree of barrelling (3). He subsequently adopted the correction factor developed by Shroeder and Webster (6). Recent publications indicate that for certain specimen geometries ($\frac{\text{Height}}{\text{diameter}}$ >2.0) the measured stress is the same with or without friction (7,8). To confirm this point, specimens with similar height to diameter ratios were deformed under the same conditions as the non-lubricated samples, but with lubricants placed into a v-shaped conncentric groove in each of the flat ends of the cylinder. The lubricants were mixtures of glasses appropriate for the test temperatures.

The flow stress curves for the lubricated and non-lubricated tests are in good agreement (Figs. 8, 9 and 10). The close agreement between the pairs of curves demonstrate the validity of Schey's proposal (7) and that the Schroeder and Webster correction is too severe. This correction at a strain of .3, for example, would be about 27 MPa as opposed to an average of 6 MPa or less than 5% shown in Figs. 8, 9 and 10. It is concluded that the measured

flow stresses for the specimen sample geometries used on the Cam Plastometer do not require a correction for frictional effects.

CAM PLASTOMETER MODIFICATIONS

Requirements

The CANMET rolling mill can readily simulate the hot rolling of plate (9). However, the Cam Plastometer is more capable of simulating the high strain rate deformations of hot-strip rolling. In Table 4, proposed requirements for simulation of hot-strip rolling are compared with the closest operating conditions of the Cam Plastometer at present. Improvements in the following areas must be made to upgrade the capability of the Cam Plastometer.

1. Data collection and activation control.
2. Screw-down drive mechanism.
3. Control of specimen temperature.
4. The design of the cam and/or cam follower system.

Data collection and activation control

The number of hits for which data can be recorded is two, although as many as four hits on one sample have been made. Data on the third and subsequent hits cannot be stored readily because data from the first two hits must be transferred first to cassettes before the Biomation recorders can be reset. This problem can be overcome by using a micro-computer to collect and store the data from the Biomation recorder between deformations. A Minc micro-computer has been selected for this task. The specifications for the computer and the Biomation recorder indicate that data could be transferred in 0.5 s leaving the recorder ready for the next deformation.

The micro-computer would also control the activation of the cam follower. This is done manually at present but, manual control could not achieve inter-hit times of 1 s.

The screw-down mechanism

The manual screw-down required to reload the sample after each hit alone consumes about 10 s. There are two methods of reducing this time significantly. The first is to use an automatic hydraulic or electro-mechanical screwdown. This would involve the purchase of a custom built unit

and would be costly and time consuming to install. An alternative is to maintain the deformation block in place and prevent its return to the start position. A schematic of such a system is shown in Fig. 11(a) and (b). This method would allow a hit to be made immediately without having to reset the die block.

Cam design

Achievement of a four-hit sequence at a constant true strain rate requires a four-lobe cam. The height of each lobe will depend on the desired strain, and the strain rate will be determined by the angle subtended by the lobe and the rotational speed of the cam.

For example, assume that the following strain and strain rates are representative of the first four passes of a hot-strip mill.

Pass No.	Engineering strain	Strain rate
1	.5	15 s^{-1}
2	.35	26
3	.35	55
4	.3	80

For an initial height of 30.5 mm and a cam rotational speed of 225 rpm the four lobes would be subtended by the following angles:

Pass No.	Lobe angle	ho*(cm)	hf*(cm)
1	62.4°	3.05	1.52
2	22.35°	1.52	.9
3	10.57°	.99	.64
4	6.01°	.64	.45

*ho - pre-deformation height, hf - post-deformation height.

The total angle taken up by the four lobes is 101.3° which leaves 64.7° between each lobe (Fig. 12). At 225 rpm, 64.7 degrees of rotation takes 0.479 s and it takes .03 s for the cam follower to move from the outposition

to the hit position. Consequently, there is enough time for insertion and removal of the cam follower between the passing of lobes. This would enable the inter-hit time to be varied from .0979 s upwards in steps of .226 s which is the time it takes for one revolution.

Any sequence of four hits of a strip schedule could be simulated in this way. The strain for each pass can be increased or decreased by changing the initial height of the sample.

SAMPLE TEMPERATURE CONTROL

To simulate adequately the hot rolling of strip, a controlled-cooling technique is essential. The present furnace set-up can provide the heat treatment and inert atmosphere needed, however the cooling rate cannot be varied. Ouchi has used inert gas as a coolant and achieved cooling rates of 30°C/s (10). The gas flow is directed at the specimen and varied to give the desired cooling rate. Liquid helium can be used to provide a very cold gas that can quench the sample in .01 seconds(11). This technique would require only minor modifications.

Although this approach is adequate for the simulation of hot-strip rolling, studies of a more fundamental nature often require alternate cycles of heating and cooling. This can be achieved by using in situ induction heating. A typical system for a compression testing machine is shown in Fig. 13 (10). This method should be adaptable to the Cam Plastometer.

SUMMARY AND CONCLUSIONS

The Cam Plastometer has been tested at strain rates between 2 and 140 s^{-1}. The test results are in good agreement with data collected when the Plastometer was commissioned for the same test conditions. Repeat tests at the same strain rate and temperature established that the 95% confidence limits at a strain of .35 is ±3%. It is concluded based on these results, that the Cam Plastometer is operating according to original design.

Tests have also established that effects of friction do not exceed 5% for the specimen geometries used and that a correction factor for friction is not necessary.

The proposed modifications to the Cam Plastometer deemed necessary to be able to simulate the hot rolling of strip are:

1. Computer controlled data collection and system activation.
2. Elimination of manual screw-down adjustments between hits.
3. Design and manufacture of a four-lobe cam.
4. Techniques for controlled cooling of the specimen.

In situ heating is not necessary for the simulation of strip rolling but should be added if thermal histories other than cooling are required and for more convenient operation. The induction heating method appears to be the most suitable.

REFERENCES

1. Hockett, J.; "Compression testing at constant true strain rates"; Proceedings of the American Society for Testing Materials 59:1309-1377; 1959.

2. Stewart, M.J.; "Cam Plastometer operation manual including theory and design"; Division report MBR R282; CANMET, Energy, Mines and Resources Canada; 1974.

3. Stewart, M.J.; "Hot deformation of C-Mn steels from 1100 to 2200°F (600 to 1200°C) with contant true strain rates from .5 to 140 s^{-1}"; Division report ERP/PMRL 75-17(J); CANMET, Energy, Mines and Resources Canada; 1975.

4. Stewart, M.J.; "The effects of niobium and vanadium on the softening of austenite during hot working"; Division report ERP/PMRL 75-18(J); CANMET, Energy, Mines and Resources Canada; 1975.

5. Stewart, M.J.; unpublished work.

6. Schroeder, W. and Webster, D.A.; "Press-forming thin sections: Effect of friction, area and thickness on pressure required"; J. Applied Physics E16: 289-294; 1949.

7. Schey, J.A. et al.; "The effect of friction on pressure in upsetting at low diameter-to-height ratios"; J. Mechanical Working Technology 6: 23-33; 1982.

8. Wiegels, H. and Herbertz, R.; "Cylinder upsetting test with high friction for the determination of the yield stress"; Stahl and Eisen 99: 1380-1390; 1979.

9. Ruddle, G.E. and Linkletter, D.E.; "Interim report on correlation of the PMRL rolling mill with the Stelco hot plate mill"; Division report MRP/PMRL 80-35(F); CANMET, Energy, Mines and Resources Canada; 1982.

10. Private communication; Ouchi, C.; Manager, Steel Products Laboratory, Technical Research Centre, Nippon Kokan, K.K.

11. Ouchi, C.; "Hot deformation behaviour and structure in austenitic steels"; Transactions of the Iron and Steel Institute of Japan 20: B141; 1980.

Table 1. Data for calculation of reproducability.
Steel chemistry - 0.8 C, 1.24 Mn, .14 S, .04 Nb, 0.3 Al, wt %.

Test No.	Strain	Strain Rate (s^{-1})	Stress (MPa)	Temp °C
1	.350	4.2	112.0	1100
2	.350	4.5	120.0	1100
3	.350	4.4	120.8	1100
4	.350	4.38	126.3	1101
5	.350	4.3	124.2	1100
6	.350	4.5	116.8	1100
7	.350	4.38	117.0	1099
8	.350	4.38	102.0*	1101
9	.350	4.49	113.0	1099
10	.350	4.90	120.5	1100

* Sample was deformed off-axis resulting in a highly skewed test sample. It is not included in the calculation of the standard deviation.

STANDARD DEVIATION = 4.752

95% CONFIDENCE LIMITS = 118.9 ± 3.58

Table 2. Flow stress data by Stewart (5) for same steel as Table 1.

Test No.	Strain	Strain Rate (s^{-1})	Stress (MPa)	Temp °C
1	.350	4.53	106.3	1100
2	.350	4.62	129.6	1100
		Average	117.9	

Table 3. Steel compositions, wt %.

	C	Mn	S	Al	P	S	V	Nb	Cr
Stewart's steel	.03	.62	.32		.004	.014	<.015	<.005	<.015
Present steel	.04	.64	.29	.055	.003	.011	<.005	<.005	<.015

Table 4. Comparison of conditions during hot strip rolling with the current capabilities of Cam Plastometer

	Hot strip Rolling	Cam Plastometer
ε (max)	.5	.7
$\dot{\varepsilon}$ (max)	140 s^{-1}	200 s^{-1}
No. of hits	4 (min)	2
Inter-hit time	4.5 - 1 s	>20 s
Cooling rate	20°C/s	<2°C/s

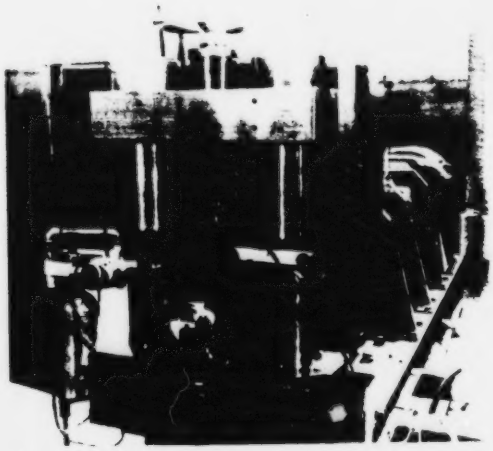


Fig. 1(a). The front view of the cam plastometer looking at the load frame. (neg 7399)

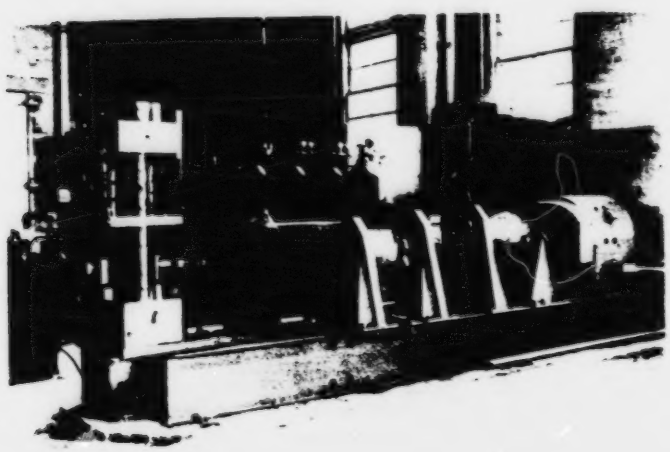
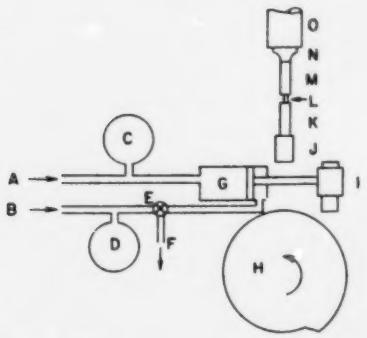


Fig. 1(b). The overall machine (a view during construction) showing the load frame and drive train. (neg 7400)



A- LOW PRESSURE IN
B- HIGH PRESSURE IN
C- SURGE TANK
D- SURGE TANK
E- SOLENOID VALVE
F- EXHAUST
G- CYLINDER
H- CAM
I- CAM FOLLOWER
J- TRANSFER BLOCK
K- LOWER DIE
L- SPECIMEN
M- UPPER DIE
N- LOAD CELL
O- PRESS SCREW

Fig. 2. Schematic of the cam follower insertion mechanism. (neg 7774)

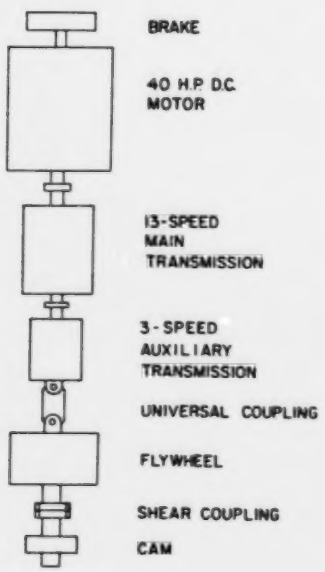


Fig. 3. Schematic of the plastometer drive train. (neg 7768)

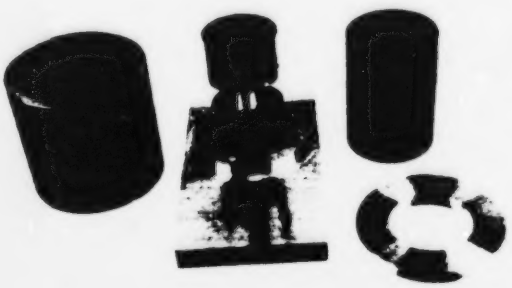


Fig. 4. Portable unit used to transfer heated specimen. (neg 7398)

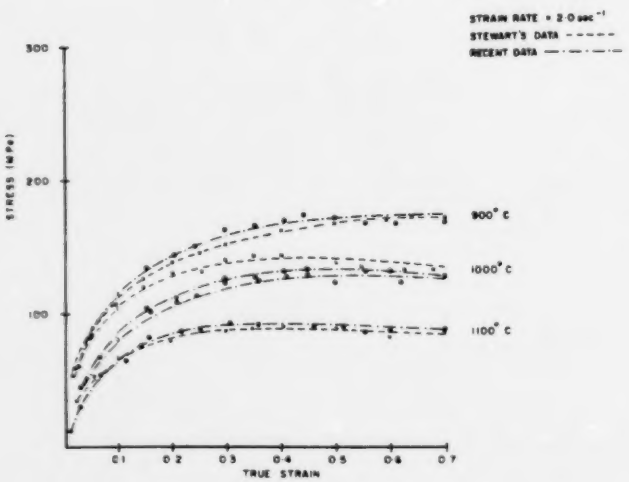


Fig. 5. A comparison of low stress data at a strain rate of 2 s^{-1}. (neg 7775)

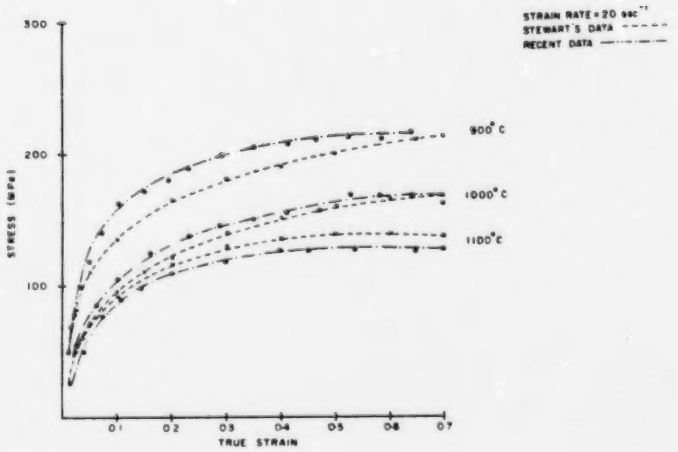


Fig. 6. A comparison of flow stress data at a strain rate of 20 s^{-1}. (neg 7776)

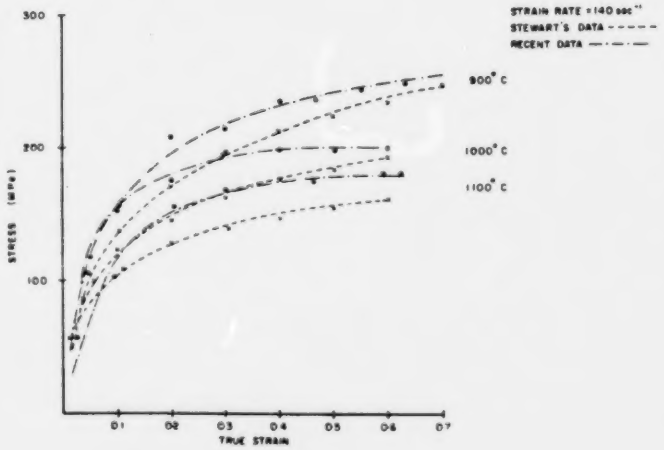


Fig. 7. A comparison of low stress data at a strain rate of 140 s^{-1}. (neg 7777).

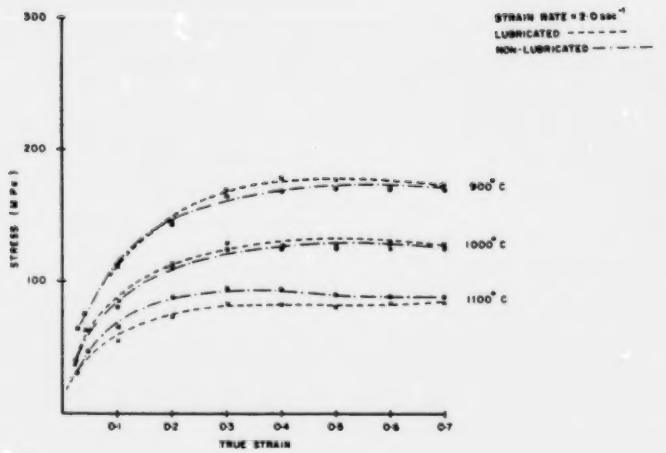


Fig. 8. A comparison of flow stress data for lubricated and non-lubricated samples. Strain rate = 20 s^{-1}. (neg 7771)

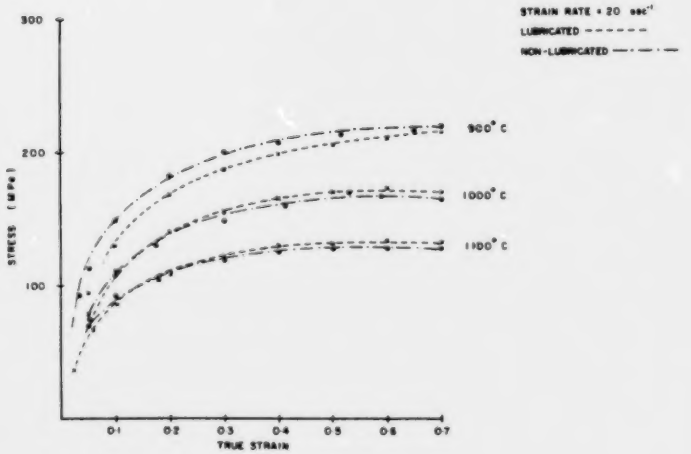


Fig. 9. A comparison of flow stress data for lubricated and non-lubricated samples. Strain rate = 20 s^{-1}. (neg 7770)

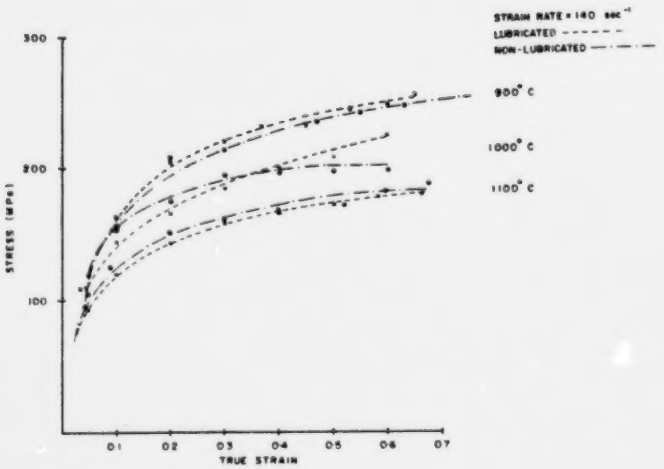


Fig. 10. A comparison of flow stress data for lubricated and non-lubricated samples. Strain rate = 140 s^{-1}. (neg 7778)

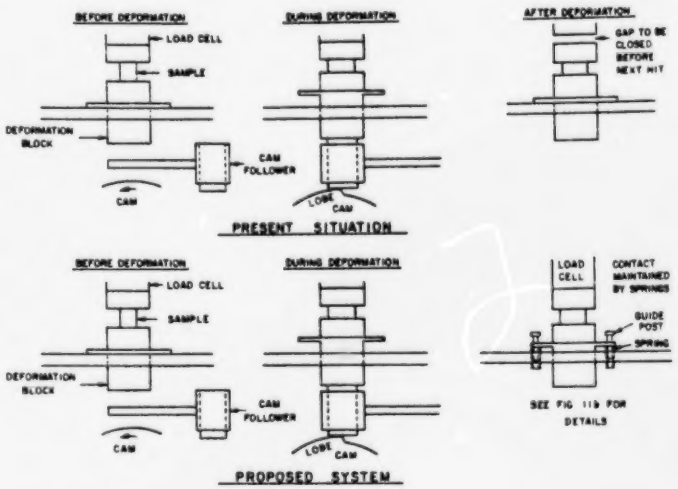


Fig. 11(a). Alternative solution to an automated screw-down mechanism. (neg 7767)

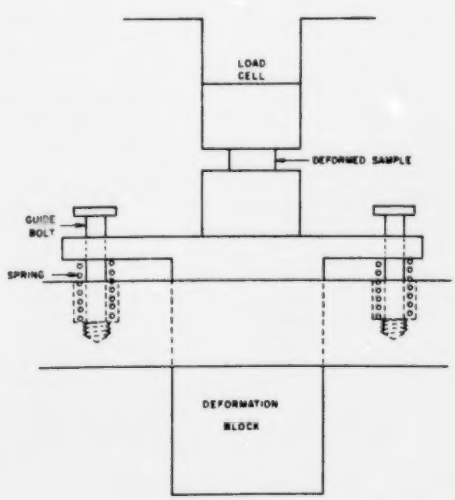


Fig. 11(b). Enlarged view. (neg 7772)

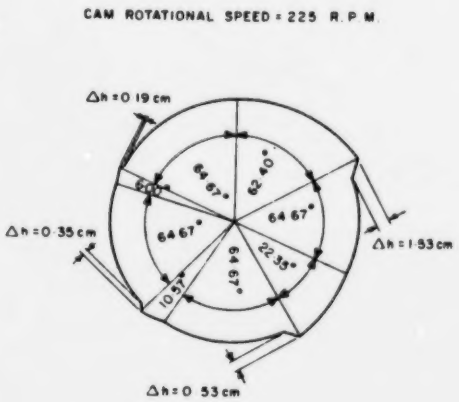


Fig. 12. Schematic of proposed cam design. (neg 7769)

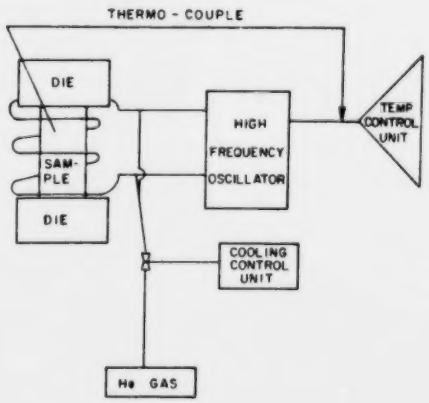


Fig. 13. Schematic of Insitu induction heating apparatus (11). (neg 7773)